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CROP PRODUCTION

Productivity and grain size of coffee grown in different weed management systems

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ABSTRACT. Intensive weed management is one of the most common practices in coffee cultivation areas. Consequently, some problems, such as soil degradation and the selection of herbicide resistant weed, have increased over time, but, if properly managed, weeds at coffee planting inter-rows can offer benefits of erosion control, nutrient recycling and crop sustainability. The aim of this study is to evaluate the effect of different weed management strategies on the productivity and coffee grain size, i.e., quality. The experiment is installed onto a resprouting *Coffea arabica* L. site, four years after it was established. Treatments are implanted at planting inter-row *Urochloa ruziziensis*, *Pueraria phaseoloides*, and spontaneous vegetation maintained by mowing, herbicides, and weeding. To measure dry matter accumulation, samples are taken with a 0.25 m^2 square template at plots maintained by mowing and herbicide application. To evaluate the yield and granulometry, coffee fruits are harvested, processed and classified in a set of 14 sieves (grouped in flat or "moca" shapes). The methods of controlling herbicide and weeding show significance in relation to grain production, with the production of grains having a higher market value standing out, when compared with the other treatments. The accumulation of dry matter above soil, in treatments with herbicides and spontaneous vegetation positively influenced the early coffee productivity (2018), and with *U. ruziziensis* and spontaneous vegetation, positively influenced the productivity of late harvest (2019). The accumulation of dry matter on the soil tends to be positively linked to coffee productivity, especially in periods when there is a shortage of rain in the region under study; however, it cannot be stated that this influence relationship (causality) has a direct positive effect between dry matter mass production and productivity of future coffee plantations.

Keywords: coffee grain yield; granulometry; split-split plot analysis; path analysis; causality; coffee bienniality.

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Introduction

Coffee cultivation is subject to a series of abiotic and biotic stresses that affect plant growth and production both quantitatively and qualitatively. Among biotic factors, it is noteworthy that the interference of weeds, which have a high competitive capacity for growth resources (water, light, and nutrients) and can hamper operations, such as crop treatment and coffee harvesting (Marcolini, Alves, Dias, & Parreira, 2009; Fialho et al., 2010; Freitas, Freitas, Furtado, Teixeira, & Silva, 2018). Weeds can cause losses of 60-80% in production, in addition to impairing the final quality of the product, if not properly controlled (Ronchi & Silva 2003; Pais et al., 2011; Moreira et al., 2013). Since the critical periods of competition between weeds and the crop occur in the period of flowering and fruiting of the crop (Fialho et al., 2010).

Classical weeding has low operational efficiency and represents high cropping cost for coffee farmers. In contrast, the usage of herbicides and appropriate application technology results in high efficiencies with low costs. However, consistently applying this method for several consecutive years can lead to the selection of weeds that are difficult to control, for example, glyphosate-tolerant species, such as *Commelina benghalensis* L. and *Spermacoce latifolia* Aubl. (Green & Owen, 2011), and resistant biotypes, such as *Conyza bonarienses* L. and *Digitaria insularis* L. (Kleinman & Rubin, 2017; Heap & Duke, 2018). In addition, maintaining the crop between the lines without vegetation cover, provided by weeds, can cause erosion and reduce the water holding capacity in the soil (Mathew, Feng, Githinji, Ankumah, & Balkcom, 2012).

Another form of weed control that has been increasingly used in coffee plantations is the mechanical control of weeds by mowing. This method favors the maintenance of cover in the soil with live or dead plant material (straw), in order to protect the soil against erosion, as well as providing nutrient cycling (Mathew et al., 2012). However, if used frequently, this method can select some small species that are not adequately controlled, such as *Commelina diffusa* Burm and *Cynodon dactylon* L., which do not provide good soil coverage, in addition to interfering with growth and coffee production.

An alternative method of weed control that has been adopted for coffee crops is the cultivation of plants that provide good soil coverage, such as some species of grasses and perennial legumes (Silva, Teodoro, & Melo, 2008; Fialho et al., 2012; Moreira et al., 2013). These species are selected for exploration according to their ability to adapt and produce biomass to form a dense vegetation cover that inhibits the emergence and growth of weeds by restricting growth resources, especially light, and also by releasing allelopathic compounds, such as the species *Urochloa ruziziensis* and *Pueraria javanica* (Benth.) Benth, also known as *Pueraria phaseoloides* (Roxb.) Benth (Foletto et al., 2012; Samedani et al., 2013). This species has been used as a cover plant and it can improve the sustainability of different agroecosystems (Teodoro, Oliveira, Silva, Fávero, & Quaresma, 2011). The cover plants, *P. phaseoloides* and *U. ruziziensis*, can favor the storage of water in the soil, the control of erosion and the release of nutrients for coffee plants, benefiting the production and improving the physical and chemical quality of the grains (Teodoro et al., 2011; Dorn, Jossi, & van der Heijden, 2015).

Weed control in coffee areas is one of the most intensive agricultural practices. Often, due to the use of inadequate weed management methods, crops are undergoing processes of soil degradation and erosion, which can interfere with coffee productivity and final product quality. Therefore, the objective of this research is to evaluate the effect of weed control strategies on the productivity and grain size of coffee grains.

Material and methods

Experiment location

The experiment was conducted in the field at the *Unidade de Ensino e Pesquisa da Horta Velha* on the Campus of the *Universidade Federal de Viçosa*, in the Viçosa city, Minas Gerais State, Brazil (20°45´14´´ S, 42°52´54´´ W and a 680 m altitude). According to (Alvares, Stape, Sentelhas, De Moraes Gonçalves, & Sparovek, 2013), the region's climate is classified as *Cwa* type, tropical in altitude, with intense rain in summer and cold, dry winters. In addition, it has an average temperature (average of 20 years) of 19.4°C (a maximum of 26.4°C and a minimum of 14.8°C) and average annual rainfall of 1,221 mm (INMET, 2008).

The research was conducted in an established coffee plantation of the species *Coffea arabica* L., cultivar Oeiras, aged four years after harvest, with a spacing of 2.80 m between rows and 0.75 m between plants, during three agricultural years (2016/2017, 2017/2018, and 2018/2019). The soil classification at the site is the Argissolo Vermelho-Amarelo distrófico, with clay texture (Table 1).

Table 1. Physical and chemical characterization of the soil in the experimental area.

Identification	pH H_2O	$H+Al^{3+}$	Al^{3+}	Ca	Mg	K	P	O.M.
		.... $cmol_c\ dm^{-3}$................				.... $mg\ dm^{-3}$....		$dag\ kg^{-1}$
0–20 cm	6.2	3.0	0	3.1	1.0	115	14.8	3.2
Identification	SB	ECEC	CEC	P-rem	V	ASI	Clay	Sand
	.... $cmol_c\ dm^{-3}$..........			$mg\ L^{-1}$	..... %		.... %	
0–20 cm	4.4	4.4	7.7	29.8	57	0	43	44

SB: Sum of exchangeable bases; ECEC: effective cation exchange capacity; CEC: cation exchange capacity pH 7.0; BSI: base saturation index; ASI: aluminum saturation index.

Initially, a liming was carried out to increase the base saturation to 70%. Later, cover fertilizations were carried out with 750 g of NPK (20-5-20) per plant/year in November, December and February, in the three years of conducting the experiment, totaling 150 g of N, 37.5 g of P_2O_5, and 150 g of K_2O per year.

Experimental design and treatments

The experiment was carried out in a randomized block design with six replications. Five treatments involving weed control strategies were evaluated (Table 2).

Table 2. Treatments adopted as a weed management strategy between coffee lines.

Treatments	Management strategy
UR	Cultivation of brachiaria (*Urochloa ruziziensis*) between rows, managed by mowing
PP	Cultivation of *Pueraria phaseoloides* between rows, managed by mowing
HB	Weed control, carried out through applications of the glyphosate herbicide, or glyphosate + 2,4-D
SV	Maintenance of spontaneous vegetation controlled by mowing
MW	Manual weeding

Each plot consisted of three rows of coffee (two between the cropping lines) with a length of 7.5 m. Each plot consisted of ten plants arranged in row, an adequate plot size for coffee yield evaluation, as recommended by Moraes et al. (2019)

Before the implementation of treatments, the crop that had been managed by mowing for more than four years was subjected to desiccation between the lines, using glyphosate (1.08 g ha^{-1}) and 2,4-D (0.536 g ha^{-1}), in November 2016, in order to homogenize the area's vegetation and enable the implementation of treatments with UR and PP.

The sowing of the brachiaria was performed manually in December 2016, with two furrows spaced 0.40 m apart, between the lines of the coffee, distributing one gram of seeds with a cultural value of 40% per linear meter of furrow. PP was implanted using seedlings obtained from vegetative propagation by rooting herbaceous cuttings in polyethylene trays containing substrate (soil + sand + bovine manure), kept in a greenhouse with programmed micro-sprinkler irrigation. After the rooting period (approximately three months), they were taken to the field and transplanted at a distance of 0.5 m, in the center of the coffee spacing, again in December 2016.

In plots where spontaneous vegetation control was carried out by applying herbicides, glyphosate (1.08 g ha^{-1}) or glyphosate + 2,4-D (1.08 + 0.536 g ha^{-1}), the applications were carried out twice a year, after the establishment of the plants in the rainy season (December) and in the period before the harvest (March), which corresponds to the end of the rainy season. The application of the association of the herbicides glyphosate + 2,4-D was carried out only once to contain the increase in the density of *C. bonarienses*. The other applications of herbicide were carried out with glyphosate alone.

The applications were carried out by means of a CO_2 sprayer pressurized to CO_2, calibrated at a constant pressure of 250 kPa, equipped with a bar, with two fan-type spray tips with air induction (TTI 11002) spaced 50 cm apart to provide the application of 200 L ha^{-1} of spray solution. At the time of the applications, the air temperature (25 ± 2°C), the relative humidity of the air (80 ± 5%) and the wind speed (3 ± 2 km h^{-1}) were measured.

In the plots maintained with spontaneous vegetation, four annual mowings were carried out. These mowings were carried out in the period of greatest rainfall in the region, which covers the months from November to March, when weeds promoted greater interference in coffee and had sufficient fresh mass to cover the soil after cutting (±50 cm in height). The treatment in which the manual weeding process was adopted here and weeding was always carried out when the weeds were between 5 and 10 cm high in order to leave bare soil.

Harvesting and processing

The evaluations related to coffee production and quality were obtained from the harvest of the fruits of eight plants in the central row, with one plant at each end discarded. The harvest was carried out by manual pulling on the cloth in the month of May of each experimental year, when at least 50% of the coffee fruits were in the cherry stage. All the fruits of the plants were harvested from the useful area of each plot. Weighing was carried out on the same day to obtain the production of "café da roça" (cherry + green + raisin) to calculate the productivity.

From the total collected in each plot, samples of three kilograms of "café da roça" were taken and placed in individual plastic nets. These were taken to dry on a terrace in full sun, where they were turned around six times a day, until the dry coffee (in coconut) was obtained with humidity of ~12%.

Yield of coffee grains through sieves

The proportion between cherry and processed coffee corresponds to the grain yield and was determined by the division between the wet and processed coffee masses. The percentage of bark present in the grains of each sample was determined by the percentage of bark mass in relation to the mass of processed grains.

Samples of 300 g of coffee in coconut were peeled in an electric peeler PA-AMO/300 to obtain processed coffee grains and calculate the yield of each sample evaluated by the method mentioned above using the ratio of the percentage of husk mass to the grain mass benefited. The processed grains were subjected to moisture measurement using a G600 coffee moisture meter.

After calculating the yield, the granulometry of the coffees was determined by means of sieves, according to the size of the grains and the size of the sieves that retain them, with circular for flat and oblong grains for "moca" grains. The classification of the size of the grains was carried out with samples of 100 g of processed coffee, evaluated in sieves interspersed according to normative instructions from the *Ministério da Agricultura, Pecuária e Abastecimento* (Brasil, 2003).

Collection of dry matter accumulation data

The evaluations of dry matter production of the aerial part for formation of mulch on the soil were carried out between the lines of the coffee. In each plot, two samples were taken using a 0.25 m^2 (0.5 × 0.5 m) hollow square, which was randomly launched between the lines. The plants were cut close to the soil, separated by species, counted, packed in paper bags and taken to the greenhouse with forced air circulation at 65°C, for 72h, to determine the dry matter mass on a precision scale.

In the treatment where weeding was carried out by means of a hoe, the evaluation of dry matter accumulation was not performed due to the fact that the plots were kept bare during the entire conduct of the experiment with no cover formation. Data on the average temperatures (maximum and minimum) and precipitation in the experimental area were recorded (Figure 1).

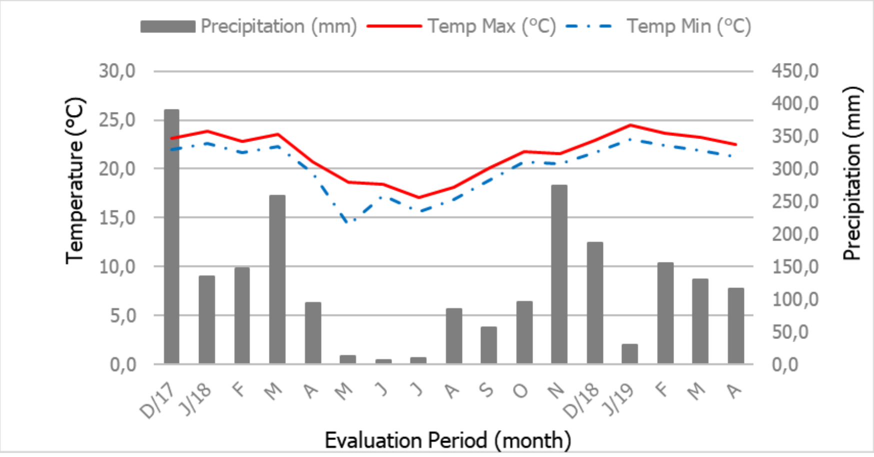

Figure 1. Average maximum and minimum temperatures (°C) and monthly precipitation (mm) observed at the UFV meteorological station during the evaluation period of December 2017 to April 2019.

Statistical analysis

The kilogram values of "café da roça" were converted to values in kilograms of processed coffee to calculate the productivity per hectare. According to Gripp (2018), for the production of 60 kg of processed coffee, ~250 kg of "café da roça" are needed.

The data obtained were evaluated by analysis of variance (ANOVA) using a model of sub-subplots. In the plots, treatments × blocks were evaluated, in the times subplots (2017, 2018, and 2019) and in the sub-subplots the sieve size classes (granulometry). The latter were evaluated by the Scott-Knott test at 5% probability. The evaluation of grain size classes as a controllable variation factor in the ANOVA model is a practice observed in other studies of the same nature (Babarinde & Fabunmi, 2009; Belay, Zemede, Assefa, Metaferia, & Tefera, 2009). Management strategies within the year were compared using Tukey's test at 5% probability.

To verify the influence of weed dry matter accumulation on the total future productivity (next year harvest) of coffee grains, causal effects were used through trail analysis. The trail diagram was built based on the productivity of the previous year and accumulation of dry matter from the weeds in the plot in previous moments (between one crop and another) over the next productivity. The 'direct' causal effects of weed dry matter mass on future productivity were computed.

Results and discussion

Total coffee grain productivity

The ANOVA indicated no significance for productivity within each year evaluated (Table 3). The management strategies did not influence the yield and total productivity of coffee grains in kg ha^{-1} in the same year of evaluation, i.e., the treatments did not differ in terms of grain size and productivity per hectare (Figure 2A).

Table 3. ANOVA considering a split-split plot design. Error A corresponds to the among-plots error, Error B is the subplot error and Error C is the sub-subplot error (i.e., the within plot error).

FV	DF	SS	MS	F	Pr(>F)	
Block	5	720087	144017	1.6478	0.193354	ns
Treatment	4	721708	180427	2.0644	0.123739	ns
Error A	20	1748026	87401			
Year	2	5549108	2774554	22.547	1.05E-07	***
Treatment × Year	8	343227	42903	0.3487	0.942029	ns
Error B	50	6152746	123055			
Sieve	14	1.35E+08	9642433	494.76	< 2.2e-16	***
Sieve × Treatment	56	1798935	32124	1.6483	0.002285	**
Sieve × Year	28	17535101	626254	32.134	< 2.2e-16	***
Sieve × Treatment × Year	112	1256585	11220	0.5757	0.999847	ns
Error C	1050	20463572	19489			

FV: Factor of Variance; DF: Degrees of Freedom; SS: Sum of Squares; MS: Mean of Squares; F: statistics of F test. Signif. codes: '***': 0.001; '**': 0.01; '*': 0.05; '.': 0.1; 'ns': 1. Coefficients of variation (CV): Error A = 101.0%, Error B = 119.9%, Error C = 47.7%.

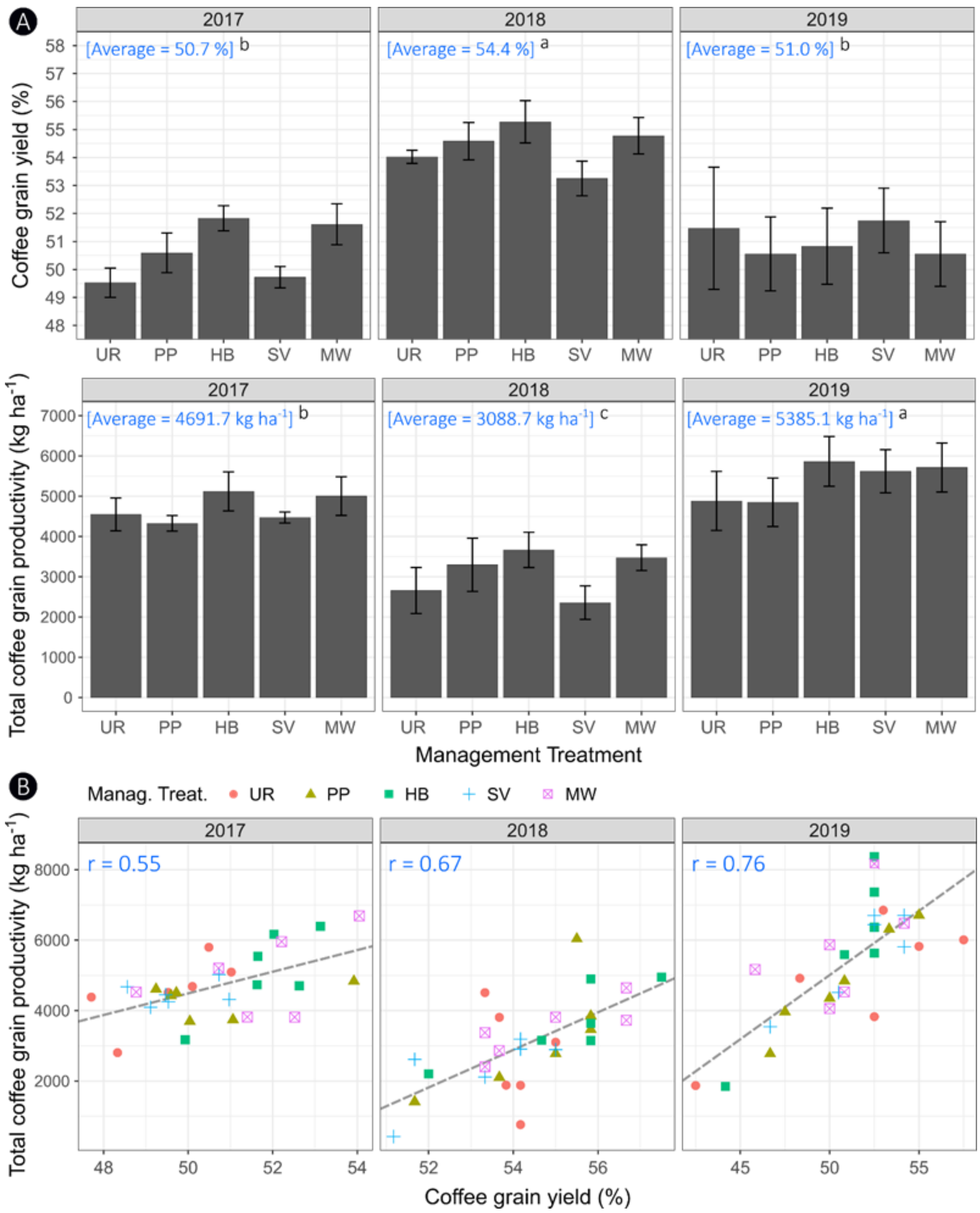

Figure 2. A) Yield and total productivity of coffee grains (in kg ha^{-1}). The boxes show the yields and productivity per year (2017, 2018, and 2019), with the annual averages shown in the upper left corner of each box. The vertical intervals in the bars correspond to the standard error of the mean, while the letters (a, b, and c) compare the treatments in the different years using the Tukey test (α = 5%). B) Correlation between the variables yield and productivity per plot in the years evaluated. UR - *U. ruziziensis* with mowing; PP - *P. phaseoloides* with mowing; HB - application of herbicides (glyphosate + 2,4-D); SV - spontaneous vegetation with mowing; MW - manual weeding.

Within each year evaluated, the treatments with the highest yield were also those with the highest productivity. However, when compared between years, productivity showed significance at the level of 5% probability (Figure 2A). The results show the effect of bienniality on coffee production, with increased productivity over the three years evaluated, which is consistent with the age of the coffee trees.

The seasonal variation between higher and lower grain yields is classified as a biennial effect, which alternates yearly. It is a physiological event that affects the productivity of arabica coffee. According to Carvalho et al. (2020), coffee plants present this marked variation in production averages and heterogeneity of phenotypic variation over the years, suggesting that progenies may be in the same physiological stage of higher and lower yields over years.

Coffee productivity at six years (2019) after receipt is statistically higher than its corresponding four years (2017) (Figure 2A). This indicates that bienniality is present but productivity had not yet stabilized in the initial condition of the experiment. This behavior is expected, since, as observed by Nascimento, Spehar, and Sandri (2014) and Pereira, Guimarães, Bartholo, Guimarães, and Alves (2007), the performance of the coffee received follows the standards of a young crop, with investment phases in vegetative growth.

Although the treatments showed no significance for total productivity between the years evaluated (Table 3), we observed a significant relationship of productivity with the subsequent years. This statement is also corroborated based on the standard error intervals observed in Figure 2A. For example, the herbicide application treatment shows greater productivity since the first year of evaluation (harvest 2017) and this productivity remains higher in the two subsequent years (harvests 2018 and 2019) when compared to the productivity of the other treatments. Similar behavior is observed for manual weeding treatment.

Considering the development logistics of each weed control method in this research, it can be observed that in the herbicide and weeding treatments, the response of the management strategy was practically immediate. This means that when these treatments were applied, the crop was in less competition for resources of the environment with weeds over time, which may have favored the higher productivity of these plots when compared with other treatments.

However, even with greater productivity in the short term, it must be considered that these two methods of weed control tend to leave the soil uncovered. This favors the action of climatic agents that cause erosion and loss of soil quality over time, which is unfavorable in terms of crop sustainability (Vieira, Giunti, Gris, & Silva, 2015; Branco & Santos, 2018).

In the UR, PP, and SV treatments, during the period of development of the species for the formation of vegetation cover, the weeds that were between the lines of the coffee competed for water and nutrients with the crop. In some months of the year, this dispute was accentuated by the scarcity of rainfall in the region, mainly in the months of January and February in 2018 and 2019 (Figure 1), which normally have higher rainfall levels.

According to Fialho et al. (2010), part of the coffee tree's absorbent roots is found on the surface of the soil, where most of the weed roots occur and in times of rain scarcity, the dispute for resources of the environment is increased. In (Moreira et al., 2013), a decrease in coffee production in levels of 60–80% was observed, when in competition with weeds, including a loss of yield and final product quality.

As it is an experiment with a perennial crop of annual production and considering that in the management strategies of *U. ruziziensis* with mowing and *P. phaseoloides* with mowing, the two species demanded a longer period for their complete establishment and formation of vegetation cover on the soil.

In the short and medium terms, it is expected that the management strategies mentioned above do not influence crop production. Furthermore, even if they result in lower productivity than the other adopted treatments, it is expected that these control methods will improve the condition of the soil, and mainly, protect it from the action of erosion, seeking the sustainability of the agroecosystem.

In each year, positive and significant correlations were observed between yield and productivity (Figure 2B). It is likely that the granulometry of the grains processed together with the amount of fruit per plant leads to greater productivity (Silva et al., 2008). A single correlation was performed per year because the treatments did not show statistical significance (Figure 2A). Over time, an increase in this correlation was observed and this value is expected to stabilize after the culture is established.

When the yield and productivity were compared between years, it was observed that the highest grain yield was not correlated with the highest fruit productivity (Figure 2A). The filling and development of the grains may have been influenced by the physiology of the plant and the climatic conditions of the period. Climatic variability is one of the factors responsible for the productive result of the crop, with the temperature conditions and water availability directly affecting grain yield (Camargo, 2010; Moreira et al., 2018).

Granulometry of coffee grains

Management strategies significantly affect the sieve yield. The ANOVA (Table 3) showed a significant difference in the treatment × classification by sieve ratio, although the management strategies did not have a significant effect on productivity per hectare of coffee (Figure 3B). Significance was observed in the grain size that presents higher market value in the herbicide and weeding treatments.

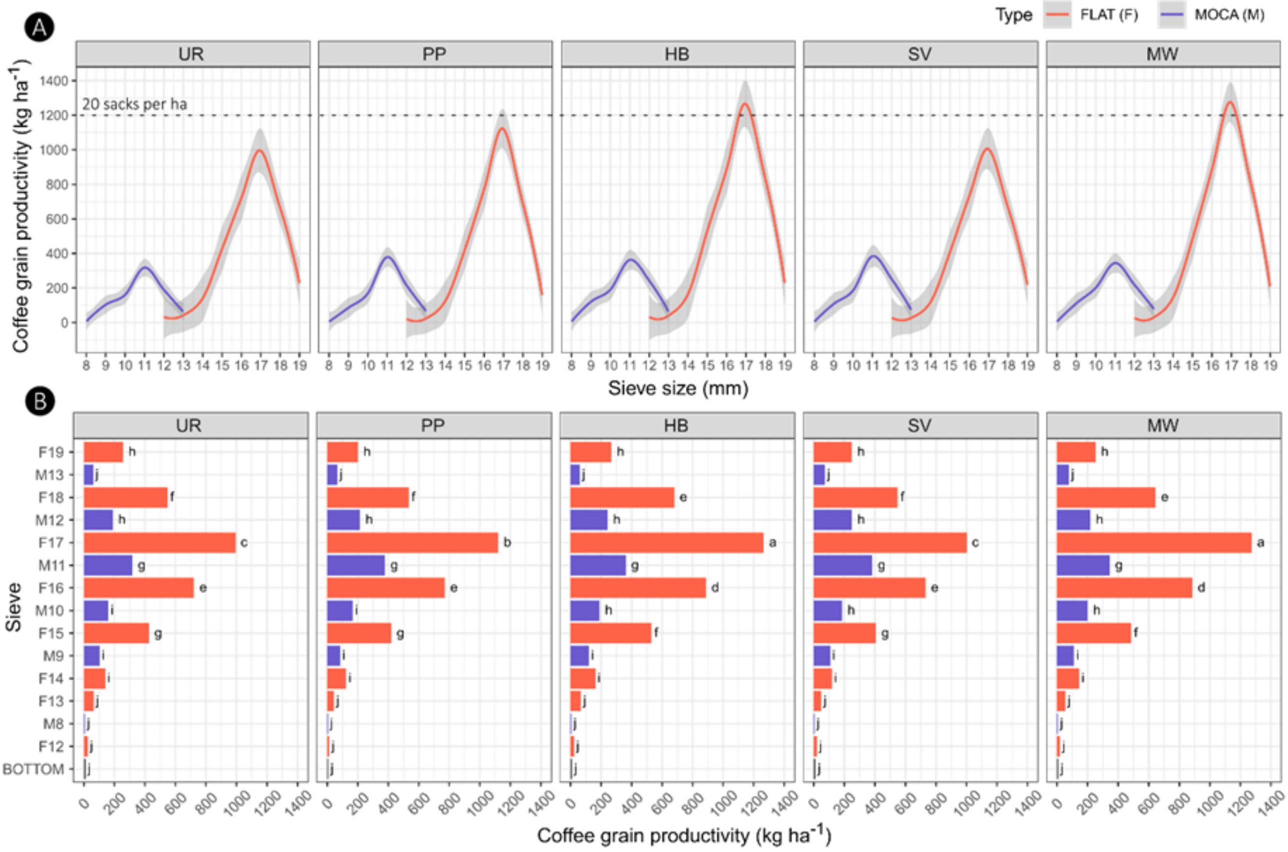

Figure 3. Relationship of grain size compared to management strategies. A) Adjusted LOESS regression showing the behavior of the accumulations of coffee grains processed through a sieve. The sieves have two types of grains (flat (red) or "moca" (blue)). The shadow around the adjustments is the standard error covering the three years of measurement. B) Scott-Knott test for the "sieve × treatment" interaction of ANOVA (Table 3). The letters (a-j) are comparable both inside and between boxes. The box titles are the five management strategies: UR - *U. ruziziensis* with mowing; PP - *P. phaseoloides* with mowing; HB - herbicide application (glyphosate + 2,4-D); SV - spontaneous vegetation with mowing; MW - manual weeding.

This result may be related to the fact that treatments with herbicide and weeding are weed management strategies that leave the soil uncovered for a longer time during a harvest. The shorter period of interference by the weed community in the crop can result in less quantitative and qualitative losses of the product (DaMatta, Ronchi, Maestri, & Barros, 2007; Ronchi, Terra, & Silva, 2007; Marcolini et al., 2009) and better results related to the grain size. Coffee classified with higher granulometry (above the 16 sieve), when associated with other quality aspects, has higher added value, as shown in Laviola, Mauri, Martinez, Araújo, and Neves (2006).

In Figure 3A, the curve of the herbicide and weeding treatments intersects the productivity line of 20 bags per hectare of flat grains sieve 17. In the PP treatment, the shadow of the standard error intercepts the productivity line of 20 bags per hectare of flat grains sieve 17. This shows the potential for greater production from the adoption of herbicide and weeding treatments and suggests good productivity from the treatment with cultivation of *P. phaseoloides* maintained by clearing (see the interception of the shade standard error and the line of 20 bags per hectare). The UR treatments with mowing and SV with mowing resulted in lower productivity (line of 20 bags per hectare), considering the classification by size 17 sieve (Figure 3A).

Although there was no uniformity for the grain size in the result of this experiment, it can be observed that the sieves of 18, 17, 16, and 15 flat granulometry (considered as large and medium granulometry) stood out. This is an interesting result when it comes to grain production with higher added value. Treatments with herbicides and weeding showed a higher amount (sacks per hectare) of flat grains sieve 17, when compared with the other treatments.

Another interesting result was that the amount of "moca" grains produced was smaller, in relation to the number of flat grains, and there was no significant difference between treatments, except between treatments with *U. ruzizienses* and *P. phaseoloides* (Figure 3B). According to Laviola et al. (2006), the fruits and the coffee grains are higher when the cultivation conditions are favorable, in this case, the lesser competition with weeds, presented by the treatments that were kept with bare soil, may have influenced the smaller amount of "moca" grains.

Still according to Laviola et al. (2006), the most demanding markets generally tolerate a maximum of 10% of soft grains for lots classified as flat grains. In seed marketing, a maximum of 12% of soft grains are tolerated. It is interesting that the lower production is for "moca" grains and the higher production is for flat to medium sized grains (Bartholo & Guimarães, 1997).

Causality of dry matter accumulation on total coffee grain yield

The accumulation of dry matter of the species between the lines of the coffee trees, in each treatment adopted, varied over time. The treatments with *U. ruzizienses* and spontaneous vegetation showed greater accumulation of dry matter, in relation to the other treatments (Figure 4A).

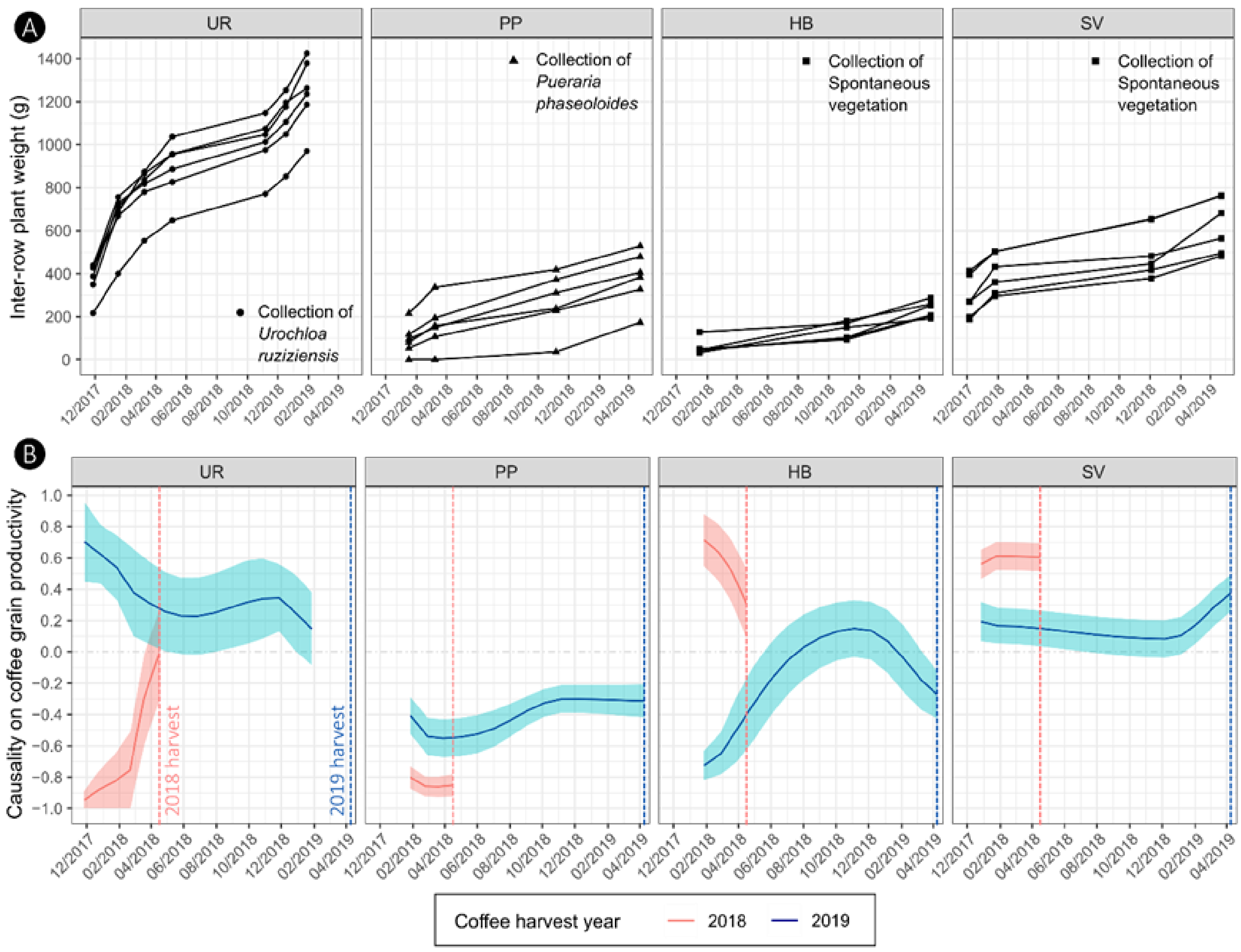

Figure 4. A) Dry matter accumulation of cover crops between the coffee lines (g m^{-2}) during the period from December 2017 to April 2019. B) Causality of the accumulation of plant dry matter between the lines on future productivity via trail analysis for the years 2018 (red) and 2019 (blue) (path analysis). The year 2017 is not shown as the biomass measurements were obtained after this year's harvest. The dashed lines indicate the timing of the two harvests (2018–2019). The box titles represent four management strategies: UR - *U. ruziziensis* with mowing; PP - *P. phaseoloides* with mowing; HB - herbicide application (glyphosate + 2,4-D); SV - spontaneous vegetation with mowing; DM - dry matter.

However, in UR, the accumulation of dry matter was greater when compared to the SV (Figure 4A), possibly due to the fact that *U. ruziziensis* has high growth capacity and straw production with a high C/N ratio that allows plant material to remain on the soil (Giacomini et al., 2003), resulting in greater accumulation.

The PP and HB treatments resulted in less variation in dry matter accumulation, when compared with the values of the treatments previously mentioned (Figure 4A). Therefore, different values for causality (influence) of dry matter accumulation in productivity were observed, according to the species studied in each plot.

In 2018 (in red in Figure 4B), the UR treatment with mowing showed a negative influence between the dry matter accumulation (in the months of December 2017 and April 2018) and the future coffee productivity. This means that the greater the dry matter accumulation, the lower the productivity of the next coffee crop, probably due to the dispute resources between the weed and the crop in this period. The species *U. ruziziensis* was in its initial growth phase, when it needs a large supply of water and nutrients to produce biomass (Souza, Townsend, Araújo, & Oliveira (2020). Another detail is that in this same period, there was a drought period between the months of January and February (Figure 1), which may have caused a dispute over water between the two species.

The coverage with *P. phaseoloides* had a negative influence of the accumulation of dry matter on productivity for all measurement moments, indicating that the productivity of the future coffee harvest in these plots will be lower, the greater the accumulation of dry matter of this legume, both for 2018 as for 2019 (in blue in Figure 4B).

Although the *P. phaseoloides* species negatively influenced the future productivity of coffee, the benefits caused by the accumulation of its plant material on the soil must be considered. In a work on a consortium of banana trees with perennial herbaceous legumes, among them *P. phaseoloides*, (Espindola et al., 2006) observed that this species had a high biomass production value, accumulated more N in the soil and derived from biological fixation, and, consequently, increased the percentage of harvested bunches and reduced harvest time, in addition to providing greater banana productivity, when compared the use of spontaneous vegetation as soil cover.

The herbicide application treatment showed a positive influence between dry matter accumulation and future coffee productivity, between January and April 2018. During this period there was a shortage of rainfall in the region (Figure 1), and at the same time little accumulation of dry matter, indicating less dispute over resources between weeds and the crop. In 2019, causality was negative in almost all moments of measurement (from February 2018 to April 2019) of the dry matter. At a time when causality is zero, the accumulation of dry matter has no effect on productivity.

The treatment SV showed a positive influence between the months of December 2017 and April 2018, the production of dry matter from spontaneous vegetation favored the productivity of the future coffee crop. In a study on nutrient accumulation by spontaneous vegetation in organic coffee cultivation, Ricci, Costa, Viana, Si, and Risso (2010) observed that plant residues from mowing spontaneous vegetation stimulated important biological processes, such as nutrient cycling, return of organic carbon to the soil, biological nitrogen fixation and helped in the control of invasive plants, which favored crop productivity.

In the year 2019 (in blue in Figure 4B), the *U. ruzizienses* and spontaneous vegetation treatments had a positive influence of the dry matter accumulation on the total productivity of coffee grains from December 2017 to April 2019. This means that the mulch formed by the different weed species found in the plots where there were *U. ruzizienses* and spontaneous vegetation, will positively influence the future coffee productivity (Figure 4B).

When weeds are in the process of development, the dispute for resources of the environment with the crop can be greater, especially in periods of water scarcity, as occurred in some months of evaluation of this work (Figure 1) and with regard to immobilization of nutrients by the weed community. Weeds have greater competitive power when compared to coffee culture (Fialho et al., 2010). However, when these are mowed, and their plant material is deposited on the soil, through nutrient cycling, these are again made available to the crop, favoring their productivity.

Studies show that the use of soil cover plants is a good management strategy for agroecosystems, enabling increases in productivity associated with the optimization of biological processes (Dias, Alves, & Lemes, 2008; Ricci et al., 2010; Melloni et al., 2013; Ronchi & Silva, 2018).

Although at times the causality between accumulation of dry matter and productivity has not had a direct positive effect, one must consider the benefits offered by the formation of mulch on the soil, even in the face of a small loss of productivity, since, currently, efforts have been made to produce sustainably. In the medium and long term, management strategies that maintain plant residues on the soil, make it possible to conserve it, mainly by avoiding soil loss due to erosion caused by climatic agents, increasing the availability of nutrients linked to organic matter and controls spontaneously occurring plants.

Conclusion

Although the management strategies adopted did not influence the total coffee productivity, herbicide and weeding treatments influenced the grain size variable, with greater production of grains over the size of a sieve 16 (coffee grains with high commercial value). The accumulation of dry matter on the soil tends to positively influence coffee productivity, especially in periods when there is a shortage of rainfall in the region under study, however it cannot be said that this influence relationship (causality) has a direct positive effect between the dry matter mass production and productivity of future coffee plantations. Within the same year, the treatments adopted did not influence coffee productivity.

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